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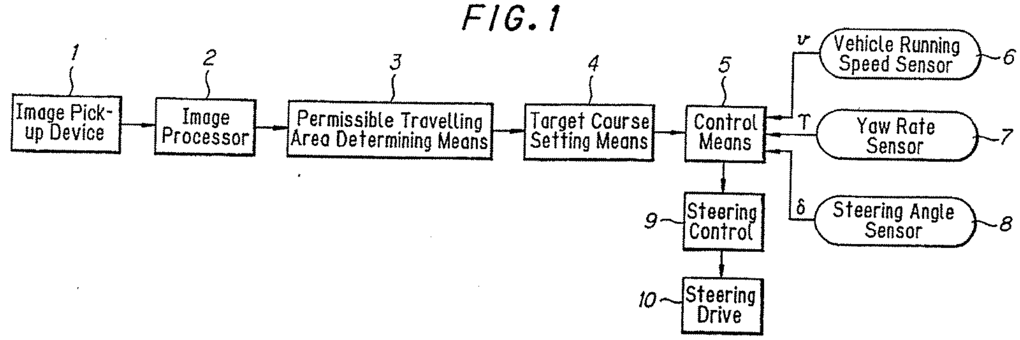
(54) **Automatic travelling apparatus.**

(57) Disclosed is an automatic travelling apparatus which is capable of taking an image of an area ahead of a vehicle by an image pick-up device attached to the vehicle; determining a permissible travelling area in the X-Y coordinates having the X-axis corresponding to the vehicle's running direction on the basis of dot unit data sampled from the taken image; setting a target course by a sequence of dots in the permissible travelling area; setting a target point on the target course at a specified distance in the X-axis direction and steering the vehicle so as to bring it to the target point, and also characterized by the possibility to convert the discontinuous dot pattern of target course into a continuous curve and to accurately set thereon the target point.

FIG. 1



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BACKGROUND OF THE INVENTION

The present invention relates to an automatic travelling apparatus capable of finding out a permissible travelling area for the purpose of permitting a vehicle to automatically run on a road.

Recently, there has been developed such an automatic travelling apparatus which is capable of finding out a permissible travelling area, setting a target course thereon and steering a vehicle so as to follow the target course.

The automatic travelling apparatus disclosed in the Japanese laid open patent publication No. 199610-88 is intended to take an image of an area ahead of a vehicle in its running direction by an image pick-up device attached to the vehicle; extract therefrom sequences of points, e.g. discontinuously dotted lines of road edges and the like, on the basis of dot image data obtained taken by data sampling of the image; determine a permissible travelling area by the X-Y coordinates in the vehicle's running direction on the basis of the extracted sequences of points; set a target course in the determined permissible travelling area; set a target point on the target course at a specified distance in X-axis direction, which calculated by multiplying an current running speed by a specified duration; a estimate a steering amount necessary for permitting the vehicle to attain the target point on the basis of the currently detected running condition such as steering angle, yaw rate (a change of angular velocity in yaw direction) of the running vehicle; and perform steering control of the vehicle to follow the target course with reference to the steering amount in a specified control cycle.

Since the above-mentioned automatic travelling apparatus sets a target point on a target course represented by a discontinuously dotted line, i.e. a sequence of points, by specifying a given distance in the X-axis direction, the target point thus determined may have a decreased accuracy, thereby causing a decrease in accuracy of steering control to follow the target course.

SUMMARY OF THE INVENTION

In view of the foregoing, the present invention was made to provide an automatic travelling apparatus which is capable of converting a target course indicated in the form of a sequence of points into a continuous curve, and accurately setting a target point on the target course thus continuously represented to assure an increased accuracy of steering control of the vehicle to follow the target course.

BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 is a block diagram showing a structure of an automatic travelling apparatus embodying the present invention.

Fig. 2 shows line segments of a road edges obtained by data processing of an image taken by a video camera.

Fig. 3 shows an image obtained by projective transformation of the image shown in Fig. 2.

Fig. 4 shows an example of a target course set in a permissible travelling area between detected road edges.

Figs. 5 (a) and 5 (b) show target courses to be set on a road, which a vehicle is to follow at a low speed (a) and a high speed (b) respectively.

Fig. 6 shows a relationship between a target course and a presumed course.

Fig. 7 shows a relationship between a vehicle's steering angle and its turning radius.

Fig. 8 shows a sequence of dots representing a target course.

Fig. 9 shows a target point being set on a target course indicated by a curve.

Fig. 10 shows a line segment in the X-Y coordinates.

Fig. 11 shows a point in the ρ-Θ point coordinates obtained by the Hough conversion of the line segment shown in Fig. 11.

Fig. 12 is a control flow chart according to the present invention.

In the drawings, 1 is an image pick-up device, 2 is an image processor, 3 is a means for determining a permissible travelling area, 4 is a means for setting a target course, 5 is a control means, 6 is a running speed sensor, 7 is a yaw rate sensor, 8 is a steering angle sensor, 9 a steering control, 10 a steering drive, 11 is a vehicle. RA is a permissible travelling area, OC is a target courses indicated by a sequence of points, OC' is a target course indicated by a curve, P is a position of a vehicle and O is a target point.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, a preferred embodiment of the present invention will be described in detail as follows:

It will be observed from Fig. 1 that an automatic travelling apparatus according to the present invention comprises: an image pick-up device 1 such as a video camera attached to a vehicle for continuously picking up subsequent images of ground ahead of the vehicle; means 2 for sampling data from images taken by the image pick-up device 1 and processing data of the dot image to extract therefrom sequences of points spaced from each other such as road edges and the like; means 3 for determining, on the basis of the obtained sequences of points, a permissible travelling area such as a road in the direction in which the vehicle is to travel; means 4 for setting a target course in the permissible travelling area thus determined; means 5 for determining the instantaneous running condition of the vehicle on the basis of an output signal from a speed sensor 6 representing the vehicle's running speed "v", an output signal from a yaw rate sensor 7 representing the yaw rate "τ" (a change of angular velocity in the yaw direction) and an output signal from a steering angle sensor 8 representing the steering angle "δ", and for estimating, on the basis of the instantaneous running condition, a steering amount for permitting the vehicle to follow the target course; and means 9 (and a steering drive 10) for steering the vehicle with reference to the steering amount.

Actually, a microcomputer aided control is used in place of means 2, 3, 4 and 5, and means 9 can be included in the microcomputer aided control, if occasions demand.

The extraction of sequences of points such as road edges from the taken image in the image processing means 2 can be made as follows:

First, each image supplied from the image pick-up device 1 is sampled in form of dot image input signal which is subjected to differentiation process for detection of the road edges. Then, an automatic threshold setting circuit in the image processing means 2 sets an optimum threshold value in consideration of the degree of shade of the road edge image information just processed. The road edge image will be subjected to binary transformation.

Alternately, first, the image may be subjected to binary transformation, and then the binary data may be subjected to differentiation. In place of binary transformation poly-digitization may be performed to express some shade details of the image.

Digitized image information will be subjected to the Hough conversion to convert the X-Y linear coordinates into the corresponding ρ-θ point coordinates, thus jointing sequential points and eliminating isolated points to provide sequences of points representing the road edges as shown in Fig. 2.

θ stands for an angle formed between the X-axis and a perpendicular from the origin of the X-Y coordinates to a line segment, whereas ρ stands for the length of the normal line. For instance, the line segment L in the X-Y coordinates in Fig. 10 is expressed as the point 01 in the ρ-θ point coordinates in Fig. 11.

On that occasion, edge tracing may be performed on the basis of binary-coded image information to obtain road edges represented by sequences of points having continuity. The Hough conversion, edge tracing and other appropriate processings may be performed simultaneously, and then synthetic judgement may be made on the results of these processings to obtain a precise road edge information.

Since the image taken by a video camera of the image pick-up device 1 represents a perspective view, the permissible travelling area determining means 3 converts the perspective road edge image as shown in Fig. 2 into a non-perspective road edge image as shown in Fig. 3 according to the known projective conversion process.

The permissible travelling area determining means 3 has a projective conversion characteristics set in consideration of the perspective characteristics of associated video cameras.

The permissible travelling area determining means 3 can determine, on the basis of the non-perspective road image obtained by projective conversion, for instance, an area between the continuous road edges E1 and E2 shown in Fig. 4 as a permissible travelling area RA in the X-Y coordinates wherein the X-axis corresponds to the direction in which the image is taken by the image pick-up device 1, i.e., the vehicle travels.

In Fig. 4, a instantaneous position of the vehicle 11 is indicated at a point "P", and the video camera of the image pick-up means 1 is mounted at a predetermined position on the vehicle whereat the point "P" may appear at the center lower point of the display screen as the origin of the X-Y coordinates.

After a permissible travelling area is determined by the permissible travelling area determining means 3, the target course setting means 4 will select a course most appropriate for running in the permissible travelling area, and will set the so selected course as a target course to follow.

Preferably, the course may be determined in consideration of the road contour and the running speed of the vehicle to meet the instantaneous travelling condition of the vehicle. However, the course may be

basically determined in consideration of the width of the road as follows:

In case that the target course setting means 4 finds that the width of the road is above a predetermined extent, and that vehicles must keep to the left, a target course OC will be set a given constant distance "w" (for instance, 1.5 meters) apart from the left edge of the road, as shown in Fig. 4.

In case that the width of the road is below the predetermined extent, a target course will be set along the center line (not shown) of the road.

The coordinates of every sequential points representing the target course in the X-Y coordinate system are stored in an internal memory of the target course setting means 4.

The divisions of the X-Y coordinates for the permissible travelling area and the target course are selected in compliance with the magnification of the video camera of the image pick-up device 1.

In Fig. 4, the trace of the vehicle from "P" to "0" represents the course actually followed by the vehicle under the control of the control means 5 until the vehicle has come to the target course OC at the point 0.

According to the present invention, it is also possible to set the most desirable target course in consideration of the running condition of the vehicle as follows:

In case that the target course setting means 4 finds that the running speed measured by the speed sensor 6 is below a predetermined speed, the target course OC will be set in conformity with the road contour as seen from Fig. 4.

When the running speed of the vehicle is higher than a predetermined speed, and when the vehicle is running a curved road as shown in Fig. 5(b), a target course OC of reduced curvature is set so as to reduce the lateral force which is applied to the vehicle.

After setting a target course in the road, the control means 5 will estimate a steering amount to permit the vehicle to follow the target course as follows:

In the control means, a course which the vehicle will run along is presumed on the basis of the currently detected running condition, a deviation of the presumed running course from the target course is calculated, a correction value of steering angle for permitting the vehicle to follow the target course is determined, and then a target steering amount is estimated therefrom.

Practically, for example, a point where the vehicle will attain in the predetermined time at the currently detected running speed is presumed on the presumed course and the target point where the vehicle has to attain is set on the target course at the distance calculated by multiplying the presumed duration by the running speed, and then lateral deviation of the presumed point from the target point is measured to finally determine thereby a corresponding correction amount of steering angle.

Referring now to Fig. 6, it is assumed that a vehicle 11 at Point "P" is to be brought to the target course OC.

First, the distance L (m) ($L = v \times T$) on the X-axis which the vehicle 11 can run in T seconds will be determined on the basis of the vehicle's running speed v (m/s) which is detected by the speed sensor 6. Then, Point N is determined in the X-axis direction at the distance L apart from Point P (i.e. from the Y-axis) whereas a target point O is set on the target course OC at the same perpendicular distance from the Y-axis as point N has. The lateral deviation $y\ell$ from Point N to Point O (on which the vehicle would be in Tm seconds if it travelled straight along the X-axis) is estimated.

Second, in like manner, the course AC which the vehicle 11 is supposed to follow will be estimated from the yaw rate T (rad/sec), and point M on the presumed course AC at the same distance from the Y-axis as point N has. Then the lateral deviation y m from Point N to Point M (on which the vehicle would be in Tm seconds if it travelled straight along the X-axis) is estimated as follows:

Let a radius of the presumed course be represented by R:

$$
\begin{aligned}
y\,m &= R - \{R^2 - (v \times tm)^2\}^{1/2} \\
&= R - R\,\{1 - \{1 - (L/R)^2\}^{1/2}
\end{aligned}
$$

When R >> L, we obtain

$$
\begin{aligned}
y\,m &= R - R\,\{1 - (L/R)^2/2\} \\
&= L^2/2R \qquad (1)
\end{aligned}
$$

Since

$$\tau = v / R \qquad (2)$$

From Equations (1) and (2)

$y\,m = L^2 \tau / 2v$ (3)

The positive sign of yaw rate T represents that the presumed course AC turns to the left whereas the negative sign indicates the presumed course turning to the right.

The yaw rate $\Delta\tau$ to which the yaw rate of the vehicle is to be corrected on the basis of the difference "e" between two deviations $y\,\ell$ and $y\,m$ will be determined from the following equation:

$\Delta\tau = e \times 2v / L^2$ (4)

Then, on the basis of the steering angle δ detected at Point P by the steering angle sensor 8, the steering amount δ' for permitting the vehicle to get on the target course OC can be determined as follows:

Referring to Fig. 7, when $R >> \ell$, the following equation can be obtained:

$\delta = \ell / R$ (5)

From equations (2) and (5) we can derive

$\delta = (\ell / v)\,\tau$ (6)

where ℓ stands for a wheelbase. According to the equation (6) the steering angle $\Delta\delta$ for correction in accordance with the yaw rate $\Delta\tau$ to be corrected can be given by the following equation:

$\Delta\delta = (\ell / v)\,\Delta\tau$ (7)

In consideration of a general equation of steering angle in relation to the running speed, i.e., substituting $\ell = (1 + Kv^2)$ into the equation (7), we can obtain

$\Delta\delta = \Delta\tau\,\{\ell\,(1 + Kv^2) / v\,)$ (8)

where "K" is a constant which is determined both from the the vehicle characteristics such as tyre characteristics, wheelbase and so on.

Therefore, a steering amount δ' for permitting the vehicle to get on the target course can be obtained by the following equation:

$\delta' = \delta + \Delta\delta$ (9)

In response to the steering amount δ' given from the control means 5 the steering control 9 issues a drive command to the steering drive 10 which in turn steers the vehicle toward the target course OC.

The above-mentioned processing operations will be repeated at an interval of a specified control cycle, thereby the steering control of the vehicle may be continuously performed to permit the vehicle to follow the target course OC successively resetable in the permissible travelling area which is successively renewable at every control cycle as the vehicle travels.

The automatic travelling apparatus according to the present invention further includes means for converting a sequence of spaced points representing a target course OC into a continuous curve whereon a target point O will be set.

The above-mentioned means is practically included in the control means 5, whereby a approximate functional curve is calculated from the dot data of a target course OC by the least square approximation.

It is well known that a sequence of points can also be approximated to a curve by other general methods such as the Fourier transformation, Lagrange's interpolation, Spline approximation and so on.

The calculation of functions of a curve being approximate to sequential dots of a target course by the least square method is described in detail as follows:

As shown in Fig. 8, a function $f = y(x)$ of the curve which is approximated by the least square method to

the target course OC represented by a sequence of points in X-Y coordinates may be given by the following equation:

$$y(x) = a_m x^n + a_{m-1} x^{n-1} + \ldots + a_1 x + a_\emptyset \ldots \quad (10)$$

In respect to all dot data $(x_1, f_1), (x_2, f_2) \ldots (x_n, f_n)$ of the target course OC the following supplementary matrix C is formed:

$$C = \begin{vmatrix} 1 & X_1{}^2 & \cdots & Xn^m \\ 1 & X_2{}^2 & \cdots & X2^m \\ & \cdots & \cdots & \cdots \\ 1 & X_n{}^2 & \cdots & X_n{}^m \end{vmatrix} \quad (11)$$

A coefficient matrix $A = C^t \cdot C$ is calculated. where C^t is a transpose of C.

$$A = \begin{vmatrix} n & \Sigma\, Xi & \cdots \Sigma\, Xi^m \\ \Sigma\, Xi & \Sigma\, Xi^2 & \cdots \Sigma\, Xi^{m+1} \\ & \cdots\cdots\cdots\cdots & \\ \Sigma\, Xi^m & \Sigma\, Xi^{m+1} & \cdots \Sigma\, Xi^{2m} \end{vmatrix} \quad (12)$$

Then, a constant vector $b = C^t \cdot f$ is determined.

$$b = \begin{vmatrix} 1 & 1 & \cdots & 1 \\ x_1 & x_2 & \cdots & x_n \\ x_1{}^1 & x_2{}^2 & \cdots & x_n{}^2 \\ & \cdots\cdots\cdots & & \\ x_1{}^m & x_2{}^m & \cdots & x_n{}^m \end{vmatrix} \cdot \begin{vmatrix} f_1 \\ f_2 \\ f_2 \\ \\ fn \end{vmatrix} = \begin{vmatrix} \Sigma\, fi \\ \Sigma\, xi\ \ fi \\ \Sigma\, xi^2\ fi \\ \\ \Sigma\, xi^m\ fi \end{vmatrix} \quad (13)$$

Finally, linear equations of $m+1$ ($A \cdot a = b$) are obtained and then coefficients aj ($j=0, 1, 2, \ldots, n$) of the function y(x) indicated in the equation (10) are calculated thereby.

By applying thus obtained function y(x) the target point O can be set on the target course OC in the following way:

For example, as shown in Fig. 9, when $X\ell$ stands for a value of distance L determined by multiplying the running speed v by the predetermined duration tm, said value $X\ell$ substituted into the function y(x) to determine a value $y\ell$, by which the target point O is specified on the target course OC' represented by an approximated continuous curve.

Fig. 12 shows a flow of control in the apparatus according to the present invention.

Namely, according to the present invention, it is possible to, in place of directly setting a target point O on a discontinuously dotted target course OC, locate the target point by use of a function y(x) representing the target course OC by a continuous curve, thereby assuring higher accuracy of target setting in respect to the target course.

As be apparent from the foregoing description, the automatic travelling apparatus according to the present invention offers such an advantage that when taking an image of ground area ahead of a running vehicle by an image pick-up device attached to said vehicle; determining a permissible travelling area in the X-Y coordinates having the X-axis corresponding to the vehicle's running direction on the basis of dot unit data sampled from the taken image; setting a target course by a sequence of points in the permissible travelling area; setting a target point on the target course at a specified distance in the running direction of the vehicle and steering the vehicle so as to bring it to the target point, it is particularly capable of converting the discontinuously dotted target course into a continuous curve and accurately setting thereon the target point, thereby assuring higher accuracy and stability of steering control for permitting the vehicle to follow the target course.

The invention as described above can be summarized as follows:

Disclosed is an automatic travelling apparatus which is capable of taking an image of an area ahead of a vehicle by an image pick-up device attached to the vehicle; determining a permissible travelling area in the X-Y coordinates having the X-axis corresponding to the vehicle's running direction on the basis of dot unit data sampled from the taken image; setting a target course by a sequence of dots in the permissible travelling area; setting a target point on the target course at a specified distance in the X-axis direction and steering the vehicle so as to bring it to the target point, and also characterized by the possibility to convert the discontinuous dot pattern of target course into a continuous curve and to accurately set thereon the target point.

Claims

1. An automatic travelling apparatus comprising:
   means for taking an image of an area ahead of a running vehicle by an image pick-up device attached to the vehicle;
   means for sampling data from the image taken by the image pick-up means;
   means for determining, on the basis of the sampled image data, a permissible travelling area ahead of the vehicle in X-Y coordinates, X-axis thereof corresponding to the vehicle's running direction;
   means for setting a target course by a sequence of points in the permissible travelling area;
   means for setting a target point on the target course at a specified distance ahead of the vehicle in the X-axis direction,
   control means for steering the vehicle to bring it to the target point,
   characterized by converting the target course from a sequence of dots into a continuous curve and setting the target point on said curve.

2. Each and every novel feature or novel combination of features disclosed in the specification and the drawing.

FIG. 1

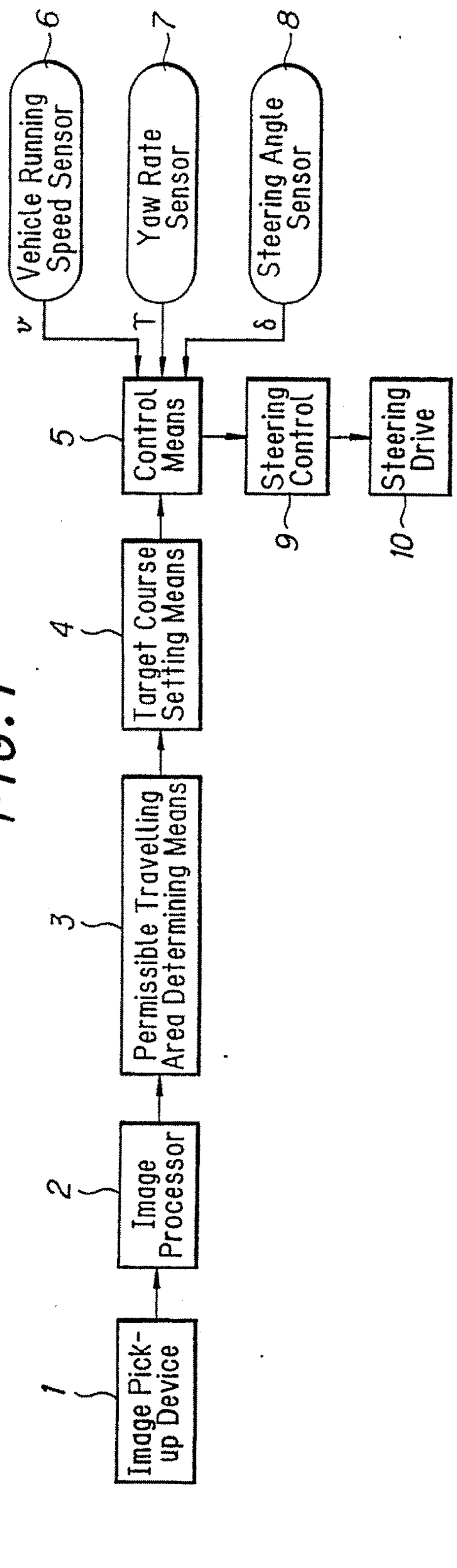


FIG. 2

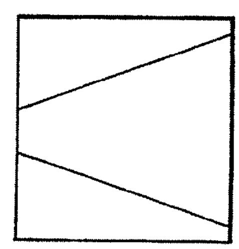


FIG. 3

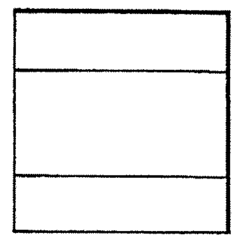


FIG.4

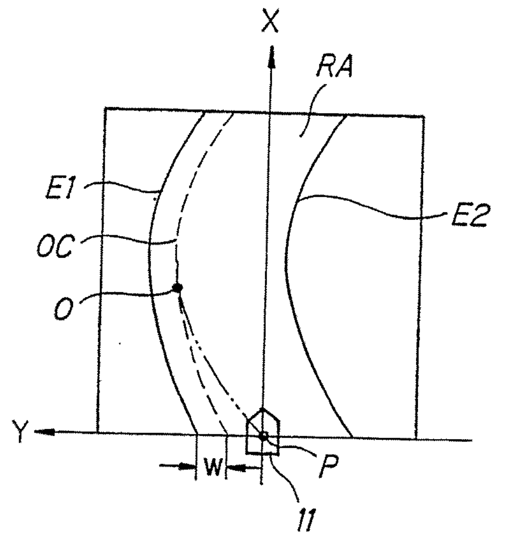


FIG.5(a)

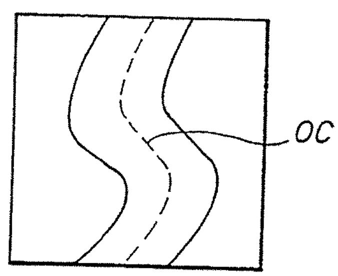


FIG.5(b)

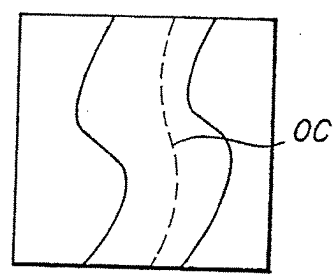


FIG.6

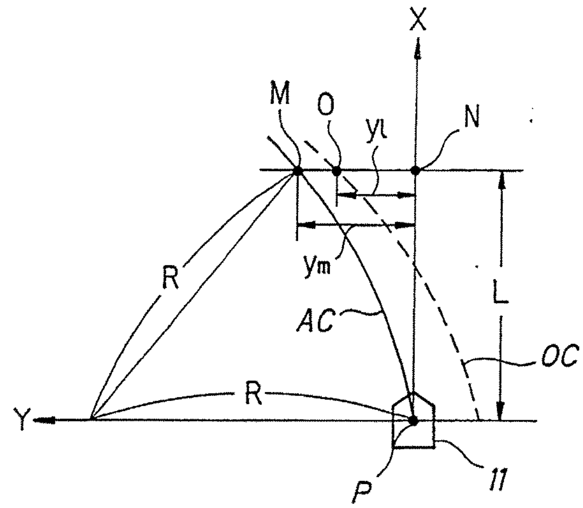


FIG.7

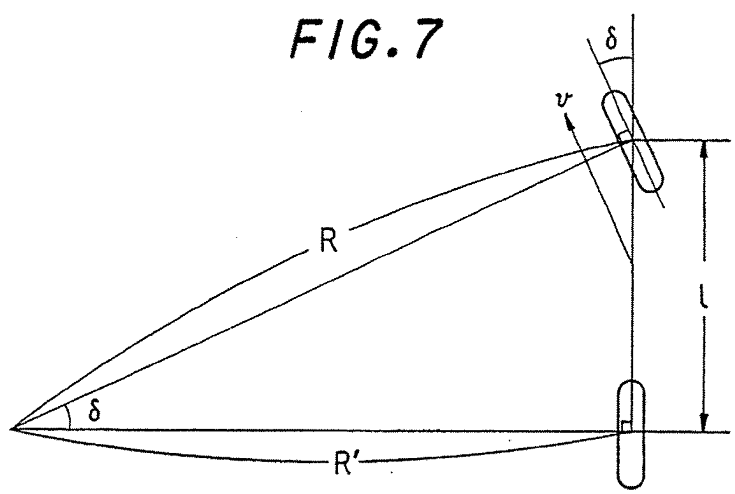


FIG.8

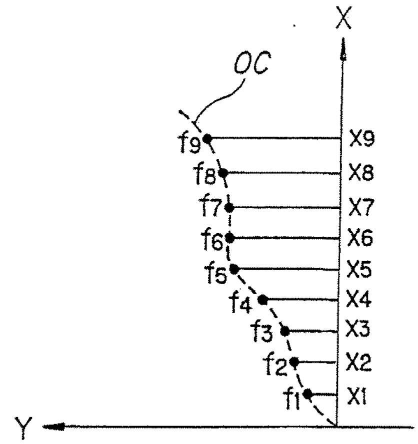

X
OC
f9
f8
f7
f6
f5
f4
f3
f2
f1
X9
X8
X7
X6
X5
X4
X3
X2
X1
Y

FIG.9

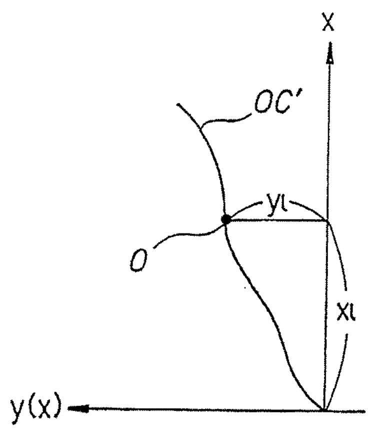

X
OC'
yl
O
xl
y(x)

FIG.10

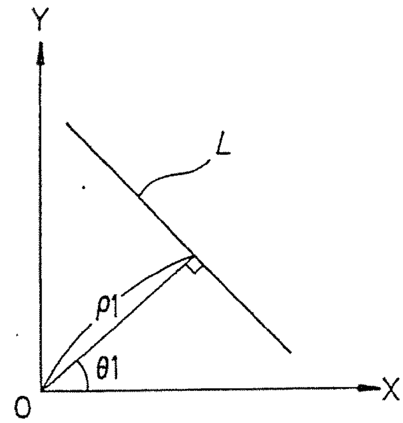


FIG.11

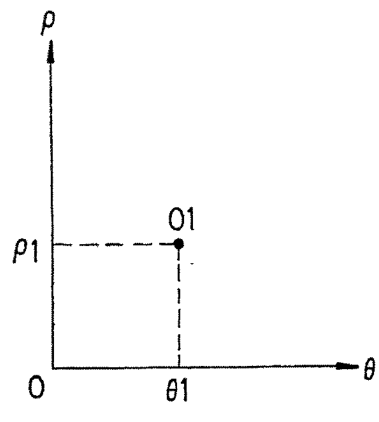
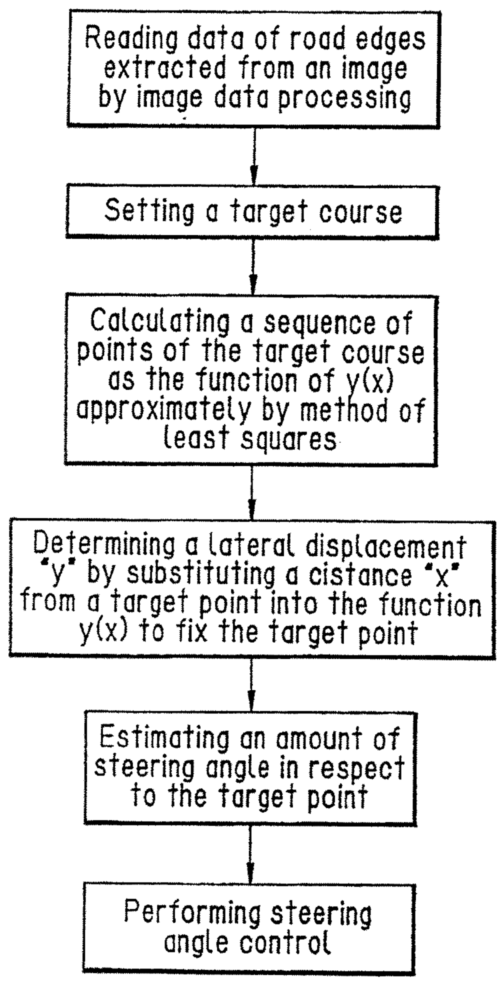


FIG. 12


Reading data of road edges extracted from an image by image data processing
Setting a target course
Calculating a sequence of points of the target course as the function of y(x) approximately by method of least squares
Determining a lateral displacement "y" by substituting a cistance "x" from a target point into the function y(x) to fix the target point
Estimating an amount of steering angle in respect to the target point
Performing steering angle control